How many bits may fit in a single magnetic dot? XMCD-PEEM evidences the switching of Néel caps inside Bloch domain walls

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HOW MANY BITS CAN FIT IN A SINGLE MAGNETIC DOT? XMCD-PEEM EVIDENCES THE SWITCHING OF NÉEL CAPS INSIDE BLOCH DOMAIN WALLS

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NANOSPECTROSCOPY

Data storage relies on the handling of two states, called bits. The market of mass storage is currently still dominated by magnetic technology, hard disk drives for the broad public and tapes for massive archiving. In these devices each bit is stored in the form of the direction of magnetization of nanosized magnetic domains. While miniaturization is the conventional way to fuel the continuous increase of device density, disruptive solutions are also sought after. To these pertain in recent years many fundamental studies no longer considering the magnetic domains themselves, but the manipulation of the domain walls (DWs). In magnetic dots of submicrometer dimensions, the magnetization has a tendency to curl along the outer edges of the nanostructure to close its magnetic flux and thereby to reduce its magnetostatic energy. Then both domains and DWs of well-defined geometries arise, whose combined manipulation has been proposed as a multilevel magnetic storage scheme. For example in nanodisks, the chirality of the flux closure and the vertical polarity of the central magnetic vortex provide two bits, which has led to many studies in recent years.

In our study we have been one step further and demonstrated the manipulation of dots with three degrees of freedom. This was achieved considering elongated dots, in which the central vortex is replaced by an elongated DW. Micrometer-sized faceted epitaxial Fe(110) dots self-assembled under ultra-high vacuum and prepared using pulsed laser deposition have been used as model systems (Figure 1(a)) [1]. Beyond its vertical polarity, such a domain wall possesses an extra degree of freedom: at both upper and lower dot surfaces the magnetization of the DW turn in-plane to minimize magnetostatic energy. These areas are called Néel caps (NCs) and are antiparallel to

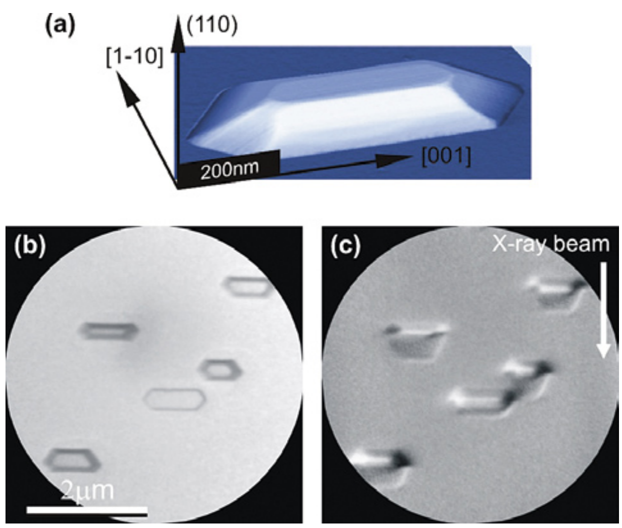

Figure 1.
(a) 3D view of a typical self-assembled epitaxial Fe(110) dot (atomic force microscopy, true aspect ratios). (b) LEEM (topography) and (c) XMCD-PEEM (magnetism) typical view of an ensemble of dots. After magnetization at -130mT all the dots are in the (-,+) state at remanence. The white arrow indicates the direction of the x-rays, thus the component of in-plane surface magnetization imaged.

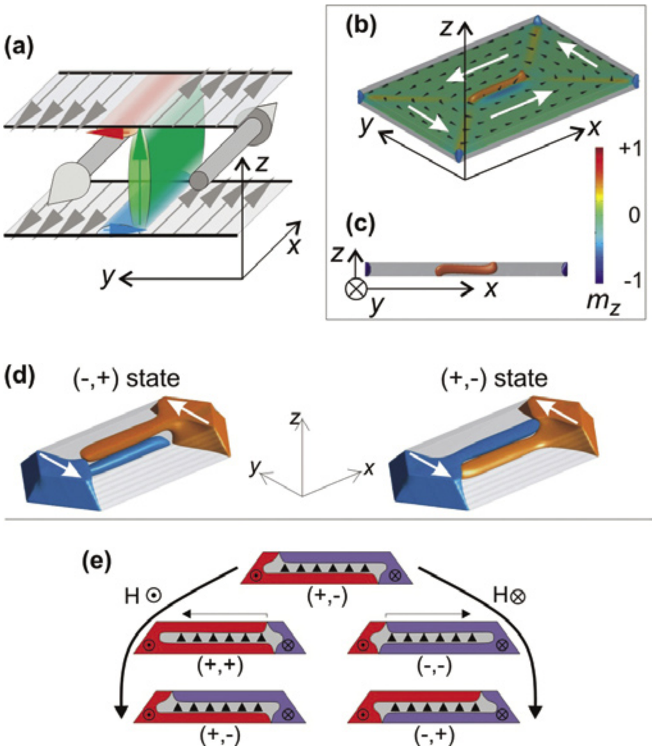

Figure 2.
(a) Schematic view of a domain wall of Bloch type, terminated by a Néel cap at each surface. The magnetization is opposite in the top and bottom Néel caps, and points along the ±y axes. (b–c) 3D and cross section views of a flux-closure state in a rectangular magnetic dot (700x500x50 nm^3). In (b) only volumes with normalized perpendicular magnetization $|m_z| > 0{:}5$ are displayed, which highlights the domain wall. The in-plane curling of magnetization is indicated by white arrows. (d) Simulation in an elongated dot of the (-,+) and (+,-) states. Only volumes with $|m_y| > 0{:}5$ are displayed, while positive and negative values appear red and blue, respectively. (e) Schematic cross-sectional view of the switching of NCs: the final state is (-,+) or (+,-) depending on the sign of the applied field.

each other in the absence of external field as seen in Figure 2(a-c) [2]. The extra degree of freedom is therefore whether the NCs are in a (-,+) or (+,-) state (Figure 2(d)). We predicted by simulation that NCs should turn parallel upon application of an external field along the short axis of the dots, while both chirality and DW polarity should remain unchanged. Then upon decreasing the field back to zero, state (+,+) switches back to (+,-), while state (-,-) switches back to (-,+), shown in Figure 2(e).
Our experimental confirmation came from the use of the French-Soleil LEEM-PEEM Elmitec instrument currently hosted at the Nanospectroscopy beamline. Exploiting the magnetic sensitivity owing to X-ray Magnetic Circular Dichroism (XMCD), the collection of emitted photoelectrons (PEEM) allows one to build surface magnetization maps with a spatial resolution around 25 nm. NCs are then revealed as a thin stripe of dark or light contrast along the length of the dots, depending on the (+,-) or (-,+) state (Figure 2(c)). As magnetic fields are hardly compatible with low-energy electrons the magnetization process was performed off-stage, and observed a posteriori. For each field several tens of dots were imaged as in Figure 1(b,c). In this way a mean switching field of 100 mT was found, in close agreement with simulations [3]. In addition, the process could be monitored in real time under applied field using Lorentz Microscopy [3].
Beyond potential applications in data storage, this study should mainly excite our physicist curiosity about the extension of the concept of magnetization reversal to the inner structure of DWs, beyond the classical case of extended domains, and trigger new studies in this direction.

References

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